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SciVerse ScienceDirect
Procedia Environmental Sciences 14 (2012) 123 – 131
Procedia Environmental Sciences

Landscape, Environment, European Identity, 4-6 November, 2011, Bucharest

Railroad-associated mortality hot spots for a population of Romanian Hermann's tortoise (*Testudo hermanni boettgeri*): a gravity model for railroad-segment analysis

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Abstract

Road-kill can lead to a sharp local decline of herpetofauna species. For this reason, transportation agencies are more and more interested to implement mitigation measures in order to eliminate this threat. The present study proposes to identify the railroad network induced threats at a railroad segment spatial scale on Getic Tableland, south-western Romania, by highlighting associated mortality hot spots for *Testudo hermanni boettgeri*. The railroad segment was chosen due to the reported road-kills and high traffic volume. In order to identify road associated mortality hot spots, we adapted a gravity model by including a weighting coefficient for overtaking obstacles. The model was adapted after observing that the cuts, fills, ditches and guardrails can change the tortoises behavior, making them avoid dangerous crossings, thus influencing the distribution of hot spots. As a main result, our study managed to adapt a gravity model for a more accurate assessment of railroad associated mortality. The average value of inter-habitat interaction is reduced by 23.37% after introducing the coefficient of overtaking the obstacles. However, despite the numerous obstacles, at a home range spatial scale, the maximum inter-habitat interaction value is not decreased, the range being stable (range = 0 - 99.66). Instead, the spatial extent of the hot spots is modified because of the increased territorial dependence and home range multi-annual stability, both severely threatening the tortoise that have a home range bisected by a major railroad. Our study accurately identifies the hot spots, which is particularly important in planning mitigation efforts, for building effective underpasses and fences systems.

Keywords: Testudo hermanni boettgeri; road-kill; gravity model; railroad related obstacles; mitigation efforts; Romania.

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doi:10.1016/j.proenv.2012.03.012

1. Introduction

Although at the European level the Hermann's tortoises (*Testudo hermanni*) are considered near threatened species, habitat loss, road-kill, illegal trade, and diseases can turn them into vulnerable ones [1]. Road mortality threat is becoming more and more obvious due to urbanization and infrastructure development all over Europe [2]. *Testudo hermanni boettgeri* or Eastern Hermann's tortoise is a strictly protected species and in Romania occurs only in the south-western part of the country [3]. A large part of the Romanian range is protected by European Natura 2000 sites [4]. The average road network density inside its range is 1.17 km/km^2 (SD = 1.24, range = 0 - 9.28) probably isolating new subpopulations which are more or less viable and, individually, are exposed to more violent threats [5].

Road ecology studies have focused not only on large mammals [6, 7] but also on herpetofauna [5, 8] [9]. There are two situations in which the road network causes the decline of different amphibians and reptiles species [10]: through road kill if roads can be crossed [9] and by habitat isolation if roads are impassable barriers [11, 12].

Methods for assessing road mortality hot spots are mainly based on landscape resistance models [13] or logistic regression models [9]. Although less used, spatial interaction models, such as gravity models, can predict the relative road associated mortality of different species [14]. Gravity models [GM] are flexible models which asses the spatial interactions between different points [15, 16, 17] and have been used in a wide variety of studies such us trade studies [18], epidemiology and invasive species dispersal [19, 20]. Only recently they were used to estimate the relative frequency of turtles movements between points located on opposite sides of the road [14]. The many cases of reported road-kill suggest that railroads are not impassable barriers for herpetofauna [11, 21], however the complete absence of tortoises from attractive habitat patches (e.g., shrubs and grasslands) can be explained by the presence of other ecological barriers [22].

Recent studies have shown that inter-habitat movements depend on the habitat quality and the distance between them [14], however, obstacles encountered by individual on his path have not been taken yet into consideration. Removing such a variable in the case of Eastern Hermann's tortoise, may result in overestimating the spatial extent of road-kill, due to biological characteristics of the species [23]. It is unclear how the tortoises behave depending on obstacles with different degrees of slope and depending on the distance from the point where the tortoise interacts with the obstacle, to the obstacle's extremities. Still their ability to overtake a railroad related obstacle can be estimated based on field observations and literature data. The introduction of a new random variable in a gravity equation was only implemented on a theoretical level [24, 15], and its usage in road ecology still remains a major challenge.

At the entire population scale, road mortality is not yet considered a severe threat [25] because tortoises does not engage in very long seasonal movements which would expose them [26], like in the case of amphibians or fresh water turtles [14, 27]. Still, in a home range bisected by a major railroad, the tortoises are exposed to more severe threats, given the species increased territorial dependence and lack of adaptability when it comes to threats [28, 29].

The aim of this study is to identify railroad-associated mortality hot spots, at a spatial scale of a railroad segment. Identifying the exact locations for intervention can facilitate conservation measures and reduce their costs.

3. Methods

1.1. Study site

The study was conducted on a railroad segment of Bucharest-Timişoara main railroad (Romanian railroad code = 900), recognized for high traffic volume. The segment is approximately 7 km long, situated on Getic Tableland from the south-western part of Romania (Fig.1) and it crosses favourable tortoises habitats, influenced by human activities such as orchards and pastures [30]. Based on spatial data digitized from 2005 aerial images, the road network density of the study area is up to 4.35 km/km^2 (mean = 2.54, SD = 0.79).

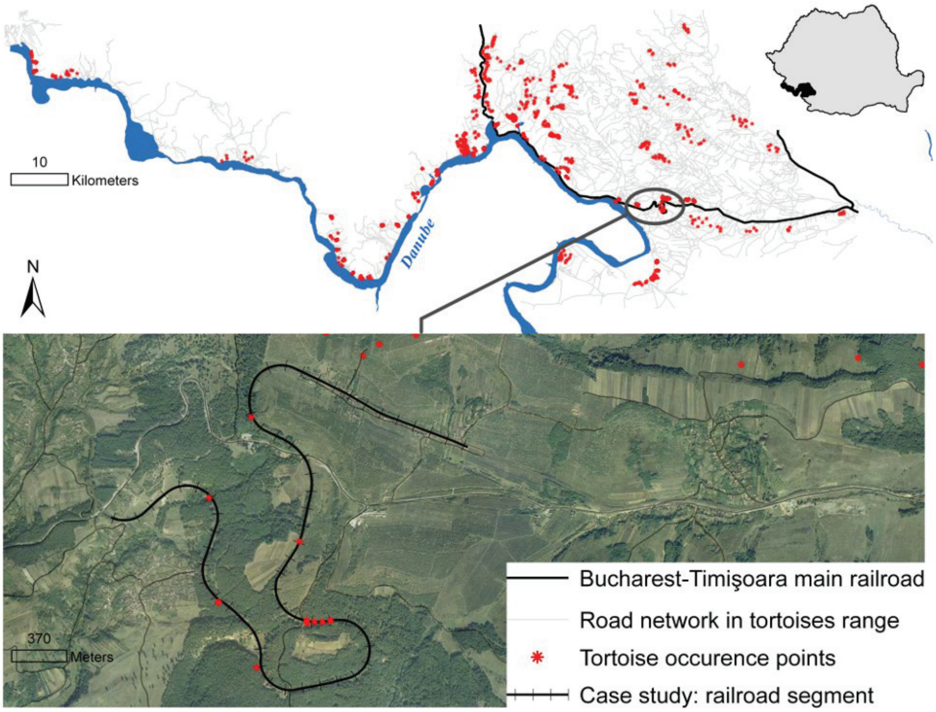

Fig. 1. Study site: a railroad segment of Bucharest-Timisoara main railroad situated on Getic Tableland, SW Romania

Adjacent obstacles such as cuts, fills, ditches, and guardrails made mostly of concrete, are found on approximately 4.4 km of the studied segment (62.4%). The railroad related obstacles have different degrees of slope (i.e. from 40° to 90°) and average lengths of 277.6 m (SD = 154.3, range = 58 - 545).

We analyzed the study area terrain slope and the average is 7.91° (SD = 5.19, range = 0 - 51.5) but after adding obstacles angles values obtained through field measurements using a raster calculator tool in a GIS we obtained an average slope of 8.19° (SD = 7.03, range = 0-90).

Because the elevation data are digitized from topographic maps at a scale of 1:25 000, the details of topographic surface are being lost. As an example, the field next to the railroad has many places with slope of 50 - 60°, covered with vegetation, which can be bypassed by tortoises. However, angles over 60° consisting of concrete or rock are becoming impassable barriers.

1.2. Gravity model

We delineate seven types of habitats with different degrees of attractiveness for Eastern Hermann's tortoise, from less attractive arable land to attractive grasslands, which offer food and shelter.

The first step of the analysis consists in calculating the selection index or attractiveness index (W_i) for each of the seven habitat classes [14, 31].

The initial equation was simplified given the lack of habitat usage data for Eastern Hermann's tortoise.

Using this simplified equation (eq. 1) we arbitrary assume that an individual can use all seven types of habitats in the study area. The guidance values obtained are presented in Table 1. Our purpose is to allow the modelling of gravity equation.

$$W_i = u_i / \sum^{n}_{j=1} \pi_{ij} \times u_j \qquad (1)$$

Where W_i is the selection index for habitat i class, u_i is the total number of i class habitat patches, π_{ij} is the proportion of available i class habitat in the study area and u_j is the total number of habitat patches regardless of their class, used by each individual.

The second variable introduced in our gravity model (i.e. distance between habitat patches centres) was obtained using Ad XY Coordinates To Table and Convert Points To Lines commands in Geospatial Modelling Environment (Spatial Ecology LLC) for creating the lines between center points located on opposite sides of the railroad segments.

Table 1. Guidance habitat attractiveness index for each of the seven habitat classes in the study site

Code	Description	Area(ha)	Habitat attractiveness (W_i)
DECIDUOUS	Large forest patches with: *Quercus* spp. *Carpinus* spp.	268.9	0.17
GRASS	Attractive patches with food resources and security: *Arenaria* ssp., *Carex* ssp., *Cardamine* ssp.	36.1	0.63
MIXT	Grassland with scattered trees	85.9	0.43
ORCHARD	Large patches with plum or apple trees	191.5	0.21
PASTURE	Large, open patches used for grazing	49.9	0.31
SHRUBS	Narrow patches of shrubs along the roads, paths, and forest edge, primarily with *Prunus spinosa, Rubus* ssp.	7.3	0.54
UNATTRACTIVE	Buildings. courtyards, arable land, paved roads	51	-

The generated lines with lengths of over 500 m were excluded from the analysis as they exceeded twice the maximum of the seasonal movements recorded for *Testudo hermanni boettgeri* [26]. We chose lines smaller than twice the maximum of seasonal movements because we consider as being potentially dangerous to cross, both the movement from starting point to interaction point and from interaction point to reaching point. Therefore we arbitrary assume that the tortoises have a linear path and can cross from both directions equally or with the same intensity.

At the crossing point of these lines with the railroad we created 418 interaction points.

The obstacle angle and the distance from the interaction point to the obstacle's extremities were obtained from field measurements.

In order to estimate the species ability to cross the danger zone bypassing the obstacles, we calibrate the GM.

The standard equation (eq. 2) was adapted to a constrained one (eq. 3), where T_{ij} represents inter habitat interaction values; k is scalar factor; W_i, W_j represents habitat attractiveness indexes; d is the distance between habitat patches centres; C is a coefficient of overtaking the obstacles. The adaptation consisted in introducing a coefficient for overtaking the obstacles (C) as a new random variable in the statistical approach of formulating and calibrating the GM [15].

$$T_{ij} = k \times W_i \times W_j / d^2 \qquad (2)$$

$$T'_{ij} = k \times W_i \times W_j \times C / d^2 \qquad (3)$$

C was proposed for linear weighting of inter habitat patches flows [15] which takes values between 0 and 1 (eq. 4), where c_1 and c_2 are coefficients of overtaking the obstacles based on distance to the obstacle's extremities and angle of the obstacle.

$$C = (c_1 + c_2)/ 2 \tag{4}$$

This weighting coefficient is a function of distance from the interaction point to the obstacle's extremities, and the angle of the obstacles. We assume the fact that there is a linear relation between the capacity of overtaking an obstacle and the two variables.

Hence a value of 1 (i.e., no cost in overtaking an obstacle) was used for the interaction points with no obstacle and a value of 0 for the interaction points with complete barriers to tortoises movements.

The functions of distance and angle (c_1, c_2) also take values between 0 and 1 and are mathematical defined as:

$$c_1 = \begin{cases} 1 - l / l_{critical}; & 0 \le l \le l_{critical} \\ 0; & l > l_{critical} \end{cases} \tag{5}$$

$$c_2 = \begin{cases} 1 - \alpha / \alpha_{critical}; & 0 \le \alpha \le \alpha_{critical} \\ 0; & \alpha > \alpha_{critical} \end{cases} \tag{6}$$

Where $l_{critical}$ and $\alpha_{critical}$ are the thresholds that force the gravity equation to 0.

The overtaking coefficient related to the distance (eq. 5) uses the value of 100 m as a critical distance. The critical value was established after the results obtained in the radio telemetry studies which concerned the Eastern Hermann's tortoise. The average daily distance travelled, for both males and females, is 31.18 m (SError = 1.59) (Laurențiu Rozylowicz, pers. comm.). Only as an exception, a tortoise moved about 200 m in the same direction [26]. The critical distance is the distance which is close to 0 as a probability to be achieved by tortoises in their attempt to overtake obstacles.

Choosing the critical value for the angle of the obstacles is partly subjective (eq. 6), this being considered the weak point of the model. Although we analyzed the average slope for 740 occurrence points, which was 10.83° (range = 0 - 58.5), we chose the $\alpha_{critical}$ mostly on field practice and observations regarding the behavior of the tortoises. Is known that tortoises prefer the sandy soils on the highest slopes for laying their eggs [32] thus the critical value was fixed at 60°, over which the tortoises can't cross.

The last step was to convert the interaction points using ArcGis Desktop 10 Geostatistical Analyst (ESRI, CA) into a 10 m cell size raster, using IDW with a fixed radius of 20 m, interpolating both the field value of T_{ij} as well as the field value of T'_{ij}.

2. Results

The presence of an obstacle in each individual's path decreases the relative frequency of tortoise movements between habitat patches on the other sides of the railroad. The average inter-habitat interaction value decrease after we entered the weighting coefficient C from 1.07 (SD = 5.38) to 0.82 (SD = 5.31) while the range is stable (range = 0 - 99.66).

The weighting coefficient C has an important effect on gravity model behaviour: it modifies the spatial distribution of the hot spots.

The distance from the interaction points to the extremities of the obstacles and the angle of the obstacles influences the capacity of the tortoises to overtake an obstacle and decreases the value of inter-habitat interaction values, down to zero. This weighting even affect the railroad segments which cross clusters of attractive habitat patches like grasslands and shrubs (Fig. 2). For example, the average inter-habitat interaction value decreased from 0.34 (SD = 0.63) to 0 for railroad segments designed with obstacles lengths > $l_{critical}$, and from 0.48 (SD = 1.40) to 0 for railroad segments designed with obstacles slopes > $\alpha_{critical}$.

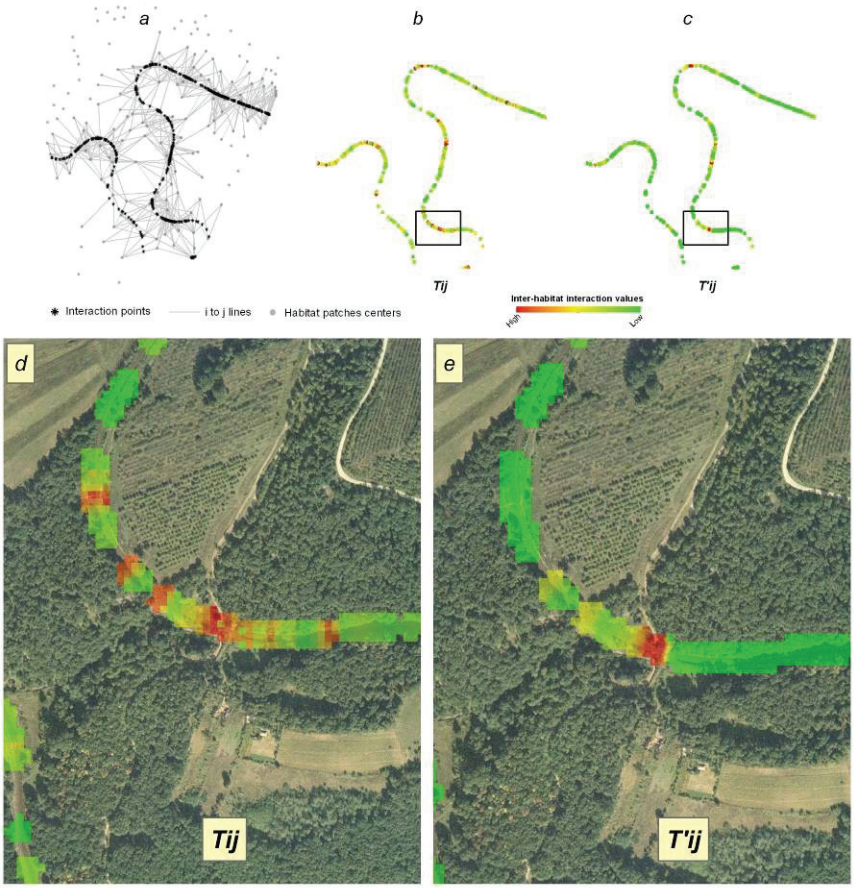

Fig. 2. Spatial interaction pattern at the railroad segment spatial scale (a) and spatial expression of gravity equation without (b) and with (c) weighting coefficient for overtaking obstacles. In the close-up, spatial extent of the hot spots is modified from a wide extending of the simple gravity equation (d) to a focused extending (e) covering a transition area from grassland to shrubs and forest

The hot spots are overlap on transition areas from grassland to shrubs and forest while cold spots are extended along the large forest patches or open pastures bisected by the railroad. We divided the railroad segment into four types of obstacles (i.e. $l_{critical}$ < 100m and $\alpha_{critical}$ <60°, $l_{critical}$ <100m and $\alpha_{critical}$ >60°, $l_{critical}$ >100m and $\alpha_{critical}$<60°, $l_{critical}$ >100m and $\alpha_{critical}$>60°). We observed that there are statistically significant differences of inter-habitat interactions values between them, caused by tortoises capacity to overtake adjacent obstacles (Kruskal Wallis $\chi^2 = 304.3$, df = 3, $p < 0.001$).

The inter-habitat interaction values are reduced through a linear relation by the spatial variation across the railroad of the distance from the interaction point up to the ends of the obstacles, and by their angle (Fig. 3). The low capacity of overtaking the obstacles does not reduce the maximum mortality in this home range, bisected by a major road, because the individuals search for water resources, food or territory, with the same intensity. This simply modify the spatial distribution of mortality hot spots, along the road segment.

3. Discussion

Our GM takes into account the biological characteristics of *Testudo hermanni boettgeri* and the species behaviour in its attempt to cross the railroad [23, 28].

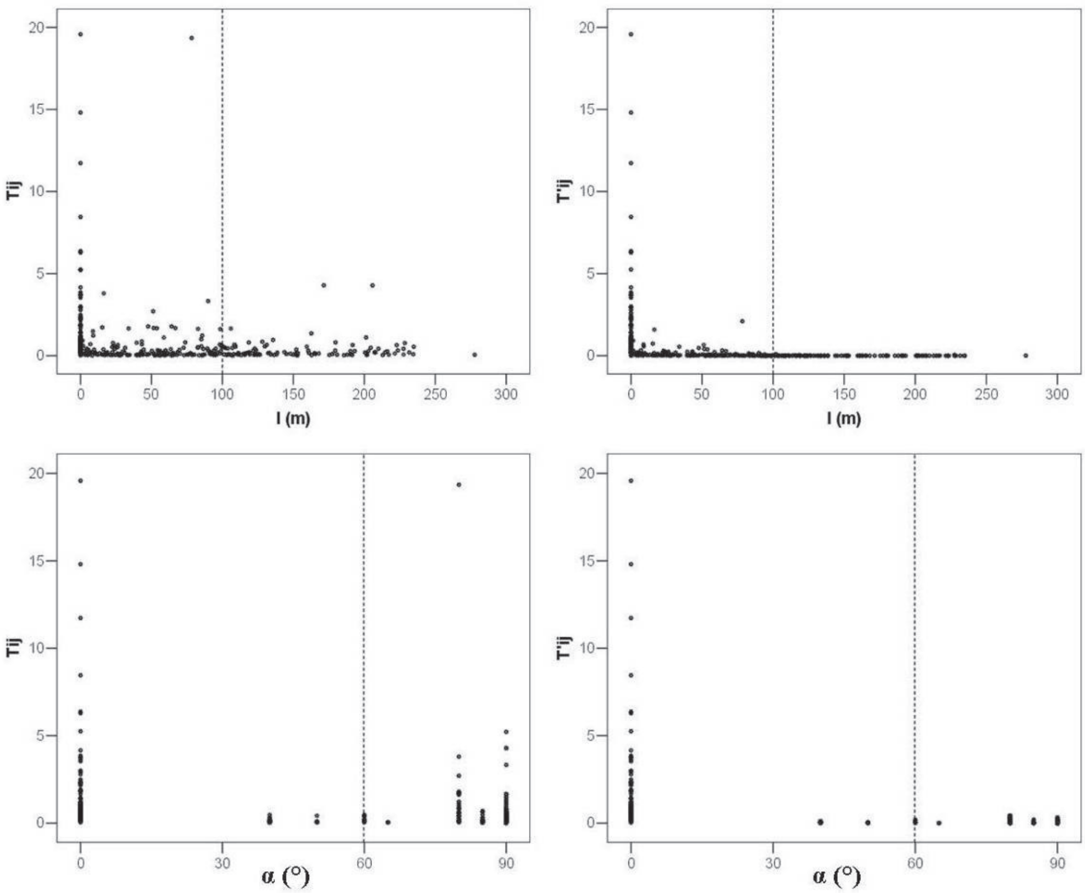

Fig. 3. Relationship between inter-habitat interaction values and the distance from interaction points to obstacles extremities (upper row) and between inter-habitat interaction values and the obstacle slope (lower row). In the left column the gravity equation does not take into account the coefficient for overtaking an obstacle. The dashed lines represent critical values of the two variables mentioned above

The adapted GM limited the spatial extension of the hot spots, being closer to the field reality, facilitating the conservation measures. Although we speculate that at a population scale, the mortality is reduced by obstacles we indicated that the impossibility to overtake them does not reduce the maximum mortality in a home range bisected by a major road, and it only modifies the spatial distribution of the hot spots along the road.

Road associated mortality (i.e. inter-habitat interaction) reached maximum values at the ends of the obstacles, in presence of attractive habitats on both sides of the railroad [14]. The highest interactions occurs where the railroad bisects fragmented patches of grassland at the forest and orchard edges where the tortoises finds both food and shelter [26].

No interaction occurs in the middle of the railroad sectors which have high concrete dams along, with an angle of over 60°, regardless of the habitat attractiveness.

Predicting the occurrence of wildlife vehicle collisions modelling variables related to obstacles or barriers, reduces the spatial errors [7] and facilitates the conservation measures. The road mortality spatial patterns for herpetofauna can be detected even after one survey [14] but we consider that adding additional road-kill points to database is required. This being usually required for temporary patterns assessment [34].

The most important limitation of our study is the use of the guidance values of the selection index for Eastern Hermann's tortoise. The second limitation it choosing the partly subjective critical values, for asses the tortoises capacity of overtaking an obstacle. There are necessary further experiments to validate this hypothesis. Access to movement data is required for a more precisely prediction of road associated mortality.

Our study suggest that it is essential to modify the gravity equation for the railroad segments without an obstacle (C = 1), by including the interactions which are deviated by the obstacles, towards their ends, since the value of the inter-habitat interaction value can grow up to the obstacles extremities.

Also significant for further studies is to model the attractiveness of the habitats which succeed in the tortoise path, from the starting point to the interaction point, as a resistance matrix [35]. Assessment of this succession, which can be determinant in selection of the interaction point for crossing the railroad, facilitates an extended road-kill analysis to population scale. The moment of the day in which the dangerous crossing event takes place, or the air temperature and the active surface temperature must be analyzed in further studies.

The validity of spatial interaction models is critical in planning mitigation efforts. Overestimating the relative frequency of tortoises movements over roads leads to wasting of financial resources and underestimating it can cause the decline of the populations whose home range is bisected by a major road.

Acknowledgements

I'am grateful to anonymous reviewers for their helpful comments and to my collegues who rigorously comment on the early versions of the manuscript. Special thanks we address to Dr. Laurenţiu Rozylowicz, for providing access to field research equipment and for his carefully guidance troughout this study.

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